THE

ELEMENTARY PRINCIPLES

OF

ELECTRIC LIGHTING

SWINTON

THE ELEMENTARY PRINCIPLES OF ELECTRIC LIGHTING

THE

ELEMENTARY PRINCIPLES

OF

ELECTRIC LIGHTING

BY

ALAN A. CAMPBELL SWINTON

ASSOCIATE OF THE INSTITUTION OF ELECTRICAL ENGINEERS

With Sixteen Illustrations.

SECOND EDITION, ENLARGED AND REVISED.

Capio Lumen

LONDON

CROSBY LOCKWOOD AND SON

7, STATIONERS' HALL COURT, LUDGATE HILL

1889

LONDON:
PRINTED BY J. S. VIRTUE AND CO., LIMITED,
CITY ROAD.

PREFACE.

THE aim of the author has been to supply the requirements of those who are anxious to obtain an elementary knowledge of the primary principles of Electric Lighting, but who have neither the time nor the inclination to read the subject at the length at which it is generally treated in text-books, and who moreover have not the mathematical aptitude and acquaintance with mechanical terms and methods that are indispensable to anyone who desires to grasp the complete theory and full details of this important though comparatively new branch of science.

As a stepping-stone to treatises of a more advanced and elaborate nature, this little work may likewise be found useful by those who purpose making a more extended study of the subject.

In the following pages the mere elements of Electric Lighting are dealt with in the simplest possible language, and the author trusts that what is given will be of service to workmen and unscientific persons, who in the first instance,

at any rate, require everything put before them in as brief and intelligible a manner as is consistent with the peculiarities of electrical phenomena and the difficulties necessarily pertaining to the principles involved.

NEWCASTLE-ON-TYNE,
February, 1886.

PREFACE TO SECOND EDITION.

IN preparing a second edition of this little book it has been considered advisable to amplify considerably several of the descriptions, and also to afford the reader some idea of the principles and construction of Transformers, which are now coming extensively into use in connection with electrical distribution from central stations.

2, PRINCES MANSIONS,
VICTORIA STREET, S.W.
December, 1888.

CONTENTS.

"I have said, and I abide by it, that the fault of most books is their being too long."

VOLTAIRE.

"A writer who has reason on his side will always be concise."

BISHOP HORNE.

ELECTRIC LIGHTING.

THE NATURE OF ELECTRICITY.

THE question, "What is electricity?" is the first that naturally presents itself, and thus at the very outset there arises what is perhaps the greatest difficulty in the whole subject, for though there are many theories as to what it is, they are theories only, and the true nature of electricity has as yet never been definitely settled.

It would be going entirely beyond the scope of this little work to enquire into all these diverse theories, and it will be sufficient to take only one, which, though very probably not scientifically correct, is yet practically adequate, and has the great advantage of being convenient and easily understood.

Though invisible, and as far as known without weight, electricity in many respects resembles a fluid, such as water, and the practical man may, without much fear of its leading him astray, regard it as such, and consider that electricity is an invisible and very subtle fluid that can be caused to flow through certain substances under certain conditions, and which produces the certain definite effects that are described later on. He must, however, remember that he only adopts this theory for the sake of convenience, and that, though it is for most practical purposes sufficient, it is very possibly as a matter of fact considerably removed from the actual truth At the same time he must bear in mind that electricity doeѕ not flow along the surfaces of bodies as do ordinary fluids, but that it passes through their substance, being in this

respect somewhat similar to heat, which also is conducted from one part of a body to another through its substance, though at a speed almost immeasurably less than is the case with electricity.

An electric current is a flow of electricity through a body or substance from one point to another, analogous in some respects to the flow of water in a pipe.

Electro-motive force, commonly written E.M.F., is what produces an electric current.

Difference of potential is what E.M.F. is due to.

In an ordinary water-pipe a difference of level or head produces a pressure which tends to cause a flow of water from where the head is higher to where it is lower; so in any body that can convey electric currents, a difference of potential at any two points in the body produces an E.M.F., which causes, or tends to cause, an electric current to flow from that point where the potential is highest to where it is lowest.

Thus difference of potential and E.M.F. in electrical science correspond very exactly to difference of head and pressure in hydraulics.

Resistance is the term employed to denote the opposition or obstruction that a body offers to the passage of an electric current. To pursue the analogy with water, electrical resistance corresponds to a certainextent with the frictional resistance which the sides of a pipe offer to the water flowing through the latter, this frictional resistance obstructing the passage of the water and diminishing the quantity that with a given pressure passes through in a given time.

All substances offer a certain amount of resistance to an electric current, just as all pipes occasion a certain amount of obstruction to a flow of water; but exactly as a large pipe will convey a certain quantity of water with greater facility than will a small one, so a large wire will offer less resistance to an electric current than a small wire.

Again, precisely as a long water-pipe offers greater obstruction to a flow of water than does a short one of the same diameter, so a long wire has a greater electrical resistance than a short one of the same thickness. In fact, the electrical resistance of a wire increases as the length of the wire is increased, and diminishes as the cross section or thickness of the wire is increased.

The electrical resistance of some substances is, however, very much greater than that of others: while some convey

electric currents very readily, others let them pass with such extreme difficulty that they may be considered almost to entirely prevent their passage. The former are called *good conductors,* the latter *bad conductors,* or *insulators.* The word non-conductor is also sometimes used, but is objectionable, as all substances are capable of conducting electricity, though some with very extreme difficulty.

The earth itself is a conductor, and in telegraphy is often made use of as such. For many reasons, however, its employment in this capacity for the purposes of electric lighting would be highly objectionable.

Silver, copper, iron, carbon, and all the metals are examples of good conductors; while glass, porcelain, ebonite, india-

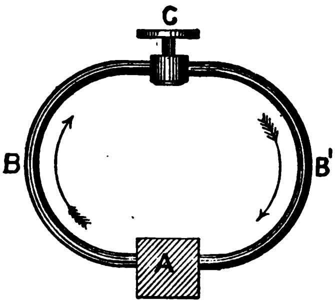

Fig. 1.—Closed Hydraulic Circuit.

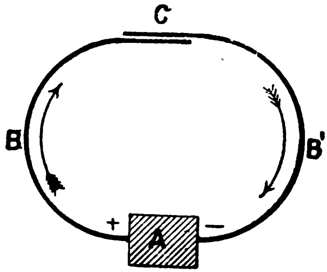

Fig. 2.—Electric Circuit.

rubber, gutta-percha, ivory, dry wood, silk, cotton, pitch, most oils, and many other substances are insulators.

All good conductors, however, do not conduct equally well, nor do all bad conductors equally resist the passage of electric currents, and there are many substances, such as common water, the human body, and others, which conduct fairly well and are called *semi-conductors.*

The term *conductivity* is frequently used by electricians to denote the specific conducting power of a substance. Thus to say that a wire is of high conductivity means that for its size it is a good conductor, in other words that it is of low specific resistance.

An electric circuit is the course or path through which an electric current flows.

Under ordinary circumstances, and invariably so far as

electric lighting is concerned, the current flows through a continuous circuit; that is to say, it always returns to the point from which it may be said to have in the first instance started, and if the circuit is broken at any point so as to prevent this return, the current immediately ceases to flow throughout every part of the circuit. In this electricity may be likened to water flowing in a closed and continuous pipe, as in Fig. 1, where A is a force-pump pumping water through the pipes B B in the direction of the arrows, the water flowing back into the pump at one end as fast as it is forced out at the other.

If now the valve or cock C be shut so as to prevent the passage of the water, the latter, provided the pipes are full, can neither move from A towards C, nor return by the other branch from C to A, and, consequently, the stream throughout the entire length of the pipe is instantaneously arrested.

If we now substitute for the pump a galvanic battery, A, Fig. 2, and for the pipes, B B, conducting wires of copper in contact with one another at C, a current of electricity will flow through the circuit formed by the wires, exactly as the water did in the pipes. The instant, however, the continuity of the circuit is broken by the ends of the two wires being separated at C, or at any other point, the electric current ceases to flow throughout the entire circuit.

Fig. 3 will help still further to explain the analogy between a flow of water in a pipe and a current of electricity in a conductor. We have here a pump, A, pumping water round and round a circuit formed of a closed horizontal pipe, B. At various points in the pipe, B, there are branch pipes C^1, C^2, &c., standing vertically.

When the pump is not working, the level of the water in the several branch pipes will clearly be the same throughout, but when the pump is actuated so as to circulate the water in the direction indicated by the arrows, it will be found that the level of the water in C^1 will rise, while in C^5 it will fall, till the water in the several branch pipes arrives at the levels shown in the illustration.

Since the levels of the water in the pipes C^1, C^2, &c., are clearly dependent on the pressures in the pipe, B, at the points where the pipes C^1, C^2, &c., branch off, this indicates that while the pump is at rest the pressure throughout B is uniform, while when the pump is working the pressure

varies from a maximum on the delivery side of the pump to a minimum on the other side.

It is of course this difference of pressure that causes the flow of water in the pipe B, the water flowing from where the pressure is greater to where it is less.

Similarly it can be shown by means of suitable instruments, that the electric potential in a conductor through which an electric current is flowing varies from end to end of the conductor, being greatest at one end and least at the other, and that it is to this difference of potential that the current is due. Moreover, exactly as the fall of pressure in the water pipe is due to the frictional resistance offered to

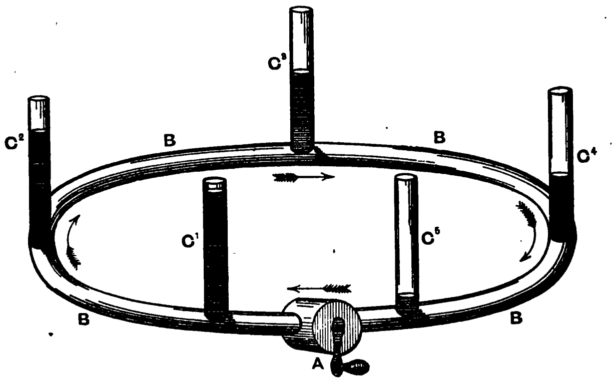

Fig. 3.

the passage of the water by the sides of the pipe, so the fall of the potential of an electric current flowing through a conductor is occasioned by the electrical resistance of that conductor, and precisely as the loss of water pressure is greater when the pipe is long, of small diameter, and with a rough internal surface, so the loss of electric potential is greater when the conductor is long, thin, and made of a material of low conductivity.

ELECTRICAL MEASUREMENTS.

Just as it is usual to employ units to gauge the quantity and pressure of water flowing through a pipe, so also there are electrical units for measuring the quantity and E.M.F. of

electric currents passing along a wire, and to these units distinctive names have been given, borrowed from the surnames of some of the greatest pioneers in electrical science.

The ampère is the unit of quantity or strength of current. We speak of an electric current of so many ampères in much the same manner as we may speak of a water current of so many gallons per minute. Instruments for measuring the strength of electric currents in ampères are called *ammeters*.

The volt is the unit of electrical pressure or E.M.F. It corresponds to the pound per square inch used to denote steam and water pressures, and is measured by an instrument called a *voltmeter*.

The ohm is the unit of electrical resistance, and here we can find no corresponding unit in hydraulics, as there is none employed to measure the friction of water in pipes, as the amount of friction varies with the velocity of the water, the number of bends in the pipe, and other causes of which it would be impossible to take accurate account. With electrical resistance, however, this is not so, and at a given temperature a wire has always the same definite resistance, whatever the strength of the electric currents flowing through it, and the position in which it is laid.

The resistance at a given temperature depends entirely upon the material of which the wire is made, the length of the wire, and its diameter; thus 100 yards of No. 8 Birmingham wire gauge iron telegraph wire has a resistance of about one ohm, while the resistance of 200 yards of the same wire would be about two ohms, and 50 yards half an ohm. In the same manner the resistance of 100 yards of a similar wire twice as thick would be half an ohm. Copper has considerably less resistance than iron, and on that account is almost invariably used as the material for electric light conductors. Thus, while as mentioned above, 100 yards of No. 8 B.W.G. iron wire has a resistance of about one ohm, 100 yards of copper wire of the same diameter has a resistance of only about one-sixth of an ohm.

Silver is the best conductor of electricity known, but its great cost precludes its employment in electric lighting, while its superiority in this respect over copper is only very slight.

Carbon, which, as hereafter shown, is extensively employed in electric lamps, has several thousand times the resistance of copper.

Relations of the Electrical Units.—Exactly as it takes a higher pressure to force the same quantity of water through a small pipe as through a larger one in the same time, so in order to maintain a constant strength of electric current in a wire, if the diameter of the latter be diminished, or its length be increased, either of which changes increases the resistance of the wire, the pressure, or E.M.F., must also be increased.

From this we get the fact that to force an electric current of the strength of one ampère through a wire, the resistance of which is one ohm, we must have an E.M.F. of one volt; and if the required current be increased to two ampères, or the resistance to two ohms, we must increase the E.M.F. to two volts.

Thus we obtain the general and most important rule, that the strength of an electric current measured in ampères is always equal to the E.M.F., or pressure of the current measured in volts, divided by the resistance of the wire or circuit through which the current is flowing, measured in ohms.

There are several other units employed by electricians, but only three of these, the horse-power, the watt, and the standard candle, need be mentioned here. *The horse-power* is a purely mechanical unit, and is employed by engineers to denote the power to do work of steam engines and other motors.

One horse-power (1 H.P.) is the power requisite to raise a weight of 33,000 lbs. one foot high, or what is the same thing, a weight of 1 lb. 33,000 feet high, in one minute of time.

A 5 H.P. engine is one that can do five times this amount of work in one minute, or do this work in one-fifth of one minute.

The watt is a unit of power now extensively employed by electricians, and is equal to $\frac{1}{746}$th part of 1 H.P.

A current of one ampère with an E.M.F. of one volt represents one watt.

The watt is therefore sometimes called the *volt-ampère.* 1,000 watts, or volt-ampères, flowing for one hour is called a *Board of Trade Unit,* this unit having been adopted by the British Board of Trade under the Electric Lighting Act of 1882. It is equivalent to about $1\frac{1}{3}$ horse-power working for one hour.

The luminous intensity or light-giving power of electric lamps is usually measured in terms of the standard candle.

A standard candle is the amount of light derived from a candle burning 120 grains of spermaceti per hour. Thus a 16 candle-power electric lamp is one giving an amount of light equivalent to 16 of these standard candles all burning at once. An ordinary gas burner usually gives a light equivalent to about 12 candles.

The candle-power of lamps is measured by an instrument called a *photometer*.

GALVANIC BATTERIES.

Galvanic batteries are arrangements for producing electric currents by means of chemical action.

In a steam engine mechanical energy is obtained by burning coal in a furnace; so in a galvanic battery electric energy is produced by consuming some material, usually the metal zinc.

If, as shown in Fig. 4, a plate of zinc, Z, and a plate of copper, C, be placed in a mixture of sulphuric acid and water contained in a glass vessel, B, and conducting copper wires, D and E, be attached to the plates Z and C respectively, we have, perhaps, the simplest possible form of galvanic battery.

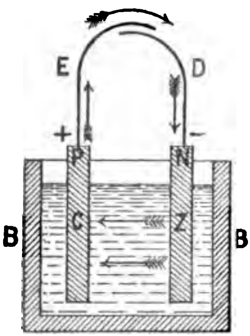

Fig. 4.—Galvanic Battery (section).

When the wires D and E are brought in contact with one another, bubbles of gas will appear on the surface of the copper plate, and detaching themselves, will rise to the surface and burst, while at the same time an electric current will pass through the wires in the direction of the arrows, from C through the wires E and D to Z, and thence back through the acidulated water to C. Should, however, the connection between the wires D and E be broken, the current will immediately cease, and the bubbles will disappear; but both will recommence on the wires being once more joined together.

If the battery be kept in action for some considerable time, it will be found that the zinc plate gradually dissolves away, and it is to this fact that the electric current is due; and the

consumption of the zinc corresponds exactly to the consumption of coal in the steam engine furnace already mentioned. In fact, to continue the hydraulic analogy previously mentioned, we may generate a current of electricity in a conducting circuit by consuming zinc in a galvanic battery in much the same manner as we can cause a flow of water through a pipe by burning coal in the furnace of a steam pumping engine.

The circuit or path formed by the wires outside the battery is called the *external circuit*, and may be of any length, while the path of the electric current inside the battery, through the liquid from the zinc to the copper plate, is called the *internal circuit.*

The points P and N, where the wires are connected to the plates, are called the *poles* of the battery, and the pole P, attached to the copper plate, which is the pole from which the electric current is supposed to flow out into the external circuit, is called the *positive* pole of the battery, while the other pole, N, attached to the zinc plate, is called the *negative* pole.

The positive pole is often marked (+), while the negative pole (—), these being the mathematical signs of addition and subtraction.

There are many different kinds of galvanic batteries of much greater power and utility than the one above described, and in some cases a large number of batteries, or cells, as they are called, are connected together in order to obtain increased effect.

In all, however, there are plates of dissimilar materials, one of which is dissolved when the battery is in action, and in every case this plate is the one in connection with the negative pole, while there is a positive pole in connection with the other plate. Galvanic batteries were originally the only known source of electricity for electric lighting. Except for very small installations they are, however, now but rarely employed, as the other means of generating electric currents, that are described below, have proved to be much more economical on a large scale.

MAGNETISM.

Every one is acquainted with the horseshoe and bar magnets of the toy shops, which are capable of attracting to them and lifting pieces of iron and steel. These magnets, which are made of very hard steel, are called *permanent* magnets, since their magnetism is more or less lasting.

A magnet, as well as a galvanic battery, has poles. The poles of a battery and the poles of a magnet have, however, no similarity except in name, and they must not be confused. In the mariner's compass a magnetic needle is pivoted at its centre so that it can turn freely in every direction, and that end of the needle which points to the north is called the north pole, or north-seeking pole of the magnet, while the other end is called the south pole.

Every magnet has its north and south poles, and these are generally situated at its extremities.

Electro-Magnetism.—If an electric current be caused to flow through a coil of wire wound round a bar of soft iron, the latter is for the time being converted into a magnet, and by employing a coil of many turns and a strong current of electricity, magnets are obtained of far greater strength than is possible with the steel permanent magnets.

In Fig. 5 we have an illustration of such an arrangement. A copper wire, A, wrapped with cotton or silk thread or covered with gutta-percha, so as to be coated all over with an insulating material, is wound round a bar of soft iron, B. If now the ends of the wire P and P′ be connected with the poles of a galvanic battery, the electric current will circulate throughout the entire length of the wire round and round the iron bar, being prevented from taking a short cut across by the insulating coat with which the wire is covered. Provided the battery be strong enough, the iron bar will be converted into a powerful magnet, and will remain such so long as the electric current continues to circulate through the wire. The moment, however, the current is interrupted, the magnetism will disappear, but will once more return when the current is permitted again to flow.

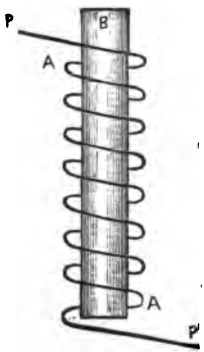

Fig. 5.—Electro-Magnet.

The electro-magnet will have poles exactly like the permanent one, but which end of the bar is the north pole and which end the south will depend entirely upon the direction of the electric current round it.

Supposing the wire to be wound as in the illustration, and P to be connected to the positive pole of the battery and P′ to the negative pole, the electric current will flow from P to

P′, that is to say, in the same direction in which the hands of a watch move, looking at the bar from the under side. If this is the case, the upper end of the bar will be the north pole, while the lower end will be the south pole; but if the direction of the current be reversed by joining P′ on to the positive pole of the battery instead of P, the poles will change places with one another, the lower end becoming north and the upper one south.

The Galvanometer.—If a magnetic compass needle, B, be pivoted at its centre and placed in a hollow coil of insulated wire, A, as shown in Fig. 6, and an electric current be caused

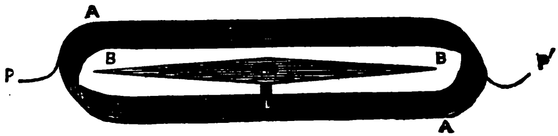

Fig. 6.—Galvanometer.

to flow through the wire by connecting its two ends P and P′ to the poles of a battery, when the current passes the needle will swing out of the coil and tend to place itself at right angles to the latter. Again, if the direction of the current in the wire be reversed, the needle will turn in the opposite direction. Galvanometers, for detecting the presence and direction of electric currents, ammeters for measuring their strength, and voltmeters for measuring their pressure, are constructed on this and similar principles.

MAGNETO-ELECTRICITY.

We have seen how an electric current can be caused to convert a soft iron rod into a magnet, it remains to show how it is possible with a magnet to produce an electric current.

Supposing the ends P and P′ of the coil of wire in Fig. 5 be connected with the ends of the coil of a galvanometer, such as is shown in Fig. 6, any electric current produced in the first coil will flow through the second one and deflect the magnetic needle.

To begin with, there will be no deflection, but if one pole of a powerful magnet of any description be brought near one

extremity of the soft iron bar B, or better still, if B be removed and the end of the magnet plunged into the interior of the coil A, an immediate movement of the needle will prove the existence of an electric current. This movement will be but momentary, and as soon as the magnet is brought to rest the needle will return to its former position, but will move again, only in an opposite direction, when the magnet is withdrawn from the coil. Moreover, it will be found that advancing the north pole of the magnet towards or into the coil will deflect the needle in the same direction as withdrawing the south pole, and also the same effects are observed when the coil is moved and the magnet remains stationary.

In every case the needle is deflected only so long as the motion of the magnet or coil continues.

These experiments prove the following remarkable facts, which are very important, since it is upon them that the working of dynamo-electric machines, which are the most economical appliances for producing large electric currents, is based.

1. When a coil of conducting wire forming the whole or part of an electric circuit is moved in the neighbourhood of a magnet, or the magnet is moved in the neighbourhood of the coil, currents of electricity are produced, or as it is called, *excited* or *induced* in the coil, which currents last only so long as the motion continues.

2. The direction of the current is governed by the polarity (whether north or south) of the end of the magnet which is nearest to the coil, and the direction of the motion (whether approach or recession) between the magnet and the coil.

3. An approaching motion between the coil and one pole of the magnet excites a current in the same direction as a receding motion between the coil and the other pole, but an approaching motion between the coil and one pole excites a current in the opposite direction to a receding motion between the coil and the same pole.

4. Hence if the coil be made to approach and recede from one pole of the magnet, the direction of the current will change every time the direction of the motion changes, and what is called an *alternating current*—that is to say, one which is alternately in one direction and alternately in the other—will be excited in the coil.

5. The more rapid the motion, the stronger the magnet,

and the more numerous the turns of wire in the coil, the stronger will be the currents generated.

DYNAMO-ELECTRIC MACHINES.

Dynamo-electric machines, often called *dynamos* for short, are merely appliances for realising these results on a large scale.

In these machines, the magnets which by their action on the coils excite the electric currents are usually called the *field magnets*, while the coils in which the currents are generated are called the *armature coils*, or simply the *armature*.

In one class of dynamo machines a number of armature coils of insulated copper wire, sometimes fitted with internal

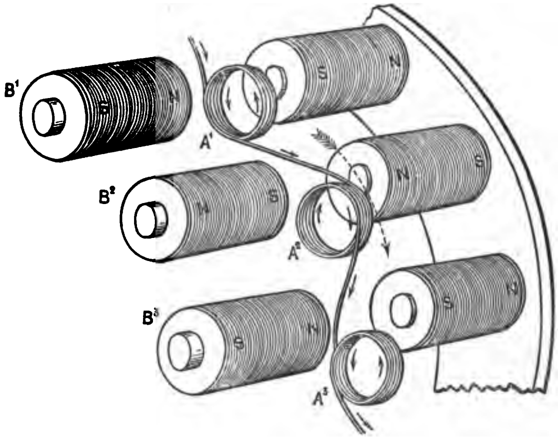

Fig. 7.—Alternate Current Dynamo.

cores of soft iron in order to increase the magnetic effect, are attached at equal distances round the circumference or edge of a circular wheel, which is mounted on an axis and is free to revolve between a number of magnets arranged on each side opposite the coils. Fig. 7 illustrates part of such an arrangement diagrammatically. A^1 A^2 A^3 are three of the armature coils revolving between the fixed pairs of magnets B^1 B^2 B^3, whose north and south poles N and S are arranged alternately opposite to one another.

If the magnets are strong and the number of turns of wire in the coils many, when the coils are caused to revolve at

great speed very powerful alternating electric currents are excited in them, and by means of fixed metallic springs or *brushes* rubbing on two insulated metal collars revolving with and connected to the coils, these currents can be led away to feed electric lamps.

In the above instance the armature coils revolve and the magnets are fixed, but in some cases it is found convenient to make the armature coils stationary and move the magnets, the ultimate effect being precisely the same in both cases.

Continuous current, as opposed to alternating current machines, are those which give off a continuous electric current constantly in the same direction into the external circuit.

Their armatures generally consist of ring-shaped or cylindrical soft iron cores, wound over with insulated wire and mounted on an axis so that they can easily be caused to revolve between the poles of large and powerful electro field magnets. As the armature rotates, the coils of wire wound

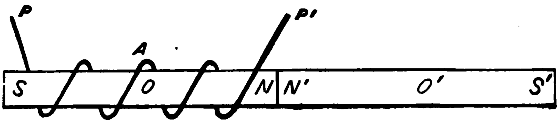

Fig. 8.

upon it pass in succession from the neighbourhood of one of the magnetic poles to the neighbourhood of another, and thus alternating electric currents are generated in them. By means of what is called a *commutator*, consisting of fixed metallic *brushes* rubbing on a number of metallic bars connected to the armature coils and revolving with them, these alternating currents are converted into ones continuously in the same direction, and from the brushes can be led away into the external circuit. Figs. 8 and 9 will help to explain the principles on which these machines work.

In Fig. 8 S N and N′ S′ are two similar bar magnets placed end to end with their two north poles, N and N′, together. A is a coil of insulated copper wire which can be made to slide backwards and forwards over the magnets from S to S′. O and O′ being the middle points of the two magnets denote their neutral or non-magnetic parts. P and P′, the two ends of the coil A, may be connected with a galvanometer so that any electric currents that are generated in the coil will

deflect the galvanometer needle one way or the other, and thus indicate their existence and direction.

Now if the coil A be caused to slide from S to O an electric current in a certain direction will be induced in the coil, producing a corresponding deflection of the galvanometer needle. If the motion of the coil be continued from O over N N′ to O′ the galvanometer needle will swing round and indicate a current in the reverse direction to the preceding one, and this reverse current will be maintained till after O′ has been passed, when the needle will once more take up its first position and indicate a current to be passing in the same direction as occurred when the coil was moving from S to O.

Now suppose that the two magnets are each bent into a semicircular form so that S touches S′, and they together form a ring, and instead of sliding the coil over the magnets, let the magnets revolve like a wheel through the coil. The conditions being exactly as before, an alternating current will be generated in the coil, and as long as the ring continues to revolve this current will be maintained.

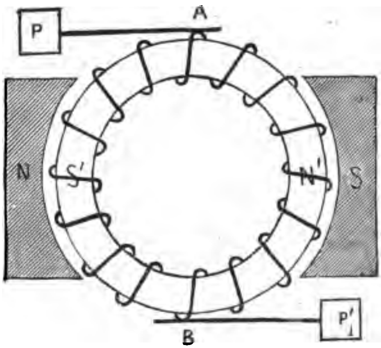

Fig. 9.

Fig. 9 shows how this principle may be applied to the production of continuous currents. N′ S′ is a soft iron ring which can be made to revolve on an axis between the poles N and S of a powerful magnet.

When a piece of soft iron is brought near one of the poles of a magnet, the iron becomes magnetised by reason of what is called *magnetic induction.* If the magnet pole be say of north polarity, the part of the piece of iron nearest to this pole becomes of south polarity and *vice versa.*

This being the case, N, the north pole of the magnet, will induce magnetism of south polarity in that part of the ring S′ that is nearest to it, and similarly the part of the ring nearest to S, the south pole of the magnet, will become magnetised to a state of north polarity.

An endless coil of insulated copper wire is tightly wound over the iron ring so as to revolve with it, the outer surfaces of this wire being bared of their insulated coating so that the fixed brass springs or brushes P and P′, which rub on the coil at the diametrically opposite points A and B, make electrical contact with the turns of wire as they brush past them.

Now it will be observed that when the ring is caused to revolve, those parts of it which are respectively opposite N and S, the north and south poles of the current, will always be magnetised so as to be themselves south and north. Hence, when the ring and coil revolve together, the polarity of the former remains stationary in relation to the magnet poles N and S, but in relation to the ring itself may be considered as passing through the coil in a direction opposite to that in which the latter is revolving. The effect is therefore similar to the stationary coil and revolving semicircular magnets described above, but with the very important difference that while in the former case the currents produced were alternating, in the latter case they are continuously in the same direction.

A very little consideration will show that this is the case. It is evident that when the ring is being revolved continuously in the same direction and the brushes P and P′ are connected together, a current will be generated in one half of the coil, say in the direction A S′ B, while another current will be generated in the other half of the coil in the direction A N′ B. A current equal to that in A S′ B added to that in A N′ B will therefore flow through the brushes, and from one to the other through the wire connecting them in the direction P′ P, P′ thus becoming the positive and P the negative poles of the machine.

The pratical details of continuous current dynamos are of course somewhat different from the above; for instance, the armature ring is wound with a great many more turns of wire than is shown in Fig. 9, and instead of arranging the brushes to rub on the wire itself, they are made to rub on a *commutator* composed of a number of parallel metal bars fastened round the circumference of the armature spindle but insulated from the latter and from one another, these bars being connected to the armature coils.

Fig. 10 is a skeleton diagram of this arrangement. A being the armature and X the spindle on which it revolves

with the commutator bars fixed round its circumference; *b* and *b′* are the two fixed brushes that rub on the bars as they and the armature revolve.

The large arrows show the direction of the rotation of the armature, and the small arrows the direction of the electric currents in the coils and connections.

In some cases the iron core on which the armature coils are wound, instead of being ring-shaped as above, is made in the form of a solid cylinder, the wires being wound on longitudinally and crossing over the ends. The connections in this case are somewhat different from that described, but the general principle is the same.

As large permanent steel magnets are costly and difficult

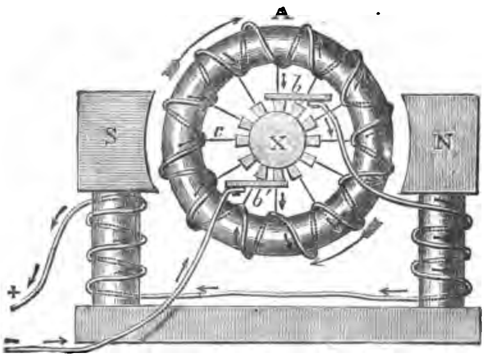

Fig. 10.—Continuous Current Dynamo.

to make, and electro-magnets are more easily obtained of the requisite power, the field magnets of dynamos are nearly always of the latter description. Alternating machines usually have a smaller continuous current machine in conjunction with them, simply for the purpose of supplying their field magnets with sufficient current to magnetise them, and are then said to be *separately excited;* but it is customary with continuous current dynamos to employ part of the current they generate to excite their own field magnets, so that the machines are what is termed *self-exciting.*

Fig. 10 shows how this may be accomplished. The wire from one of the brushes, *b*, is coiled round the legs of the electro-magnet S N, so that the current passes round

these, as indicated by the small arrows, before passing out to the lamps or whatever forms the external circuit. When a machine of this kind is first started, the magnetism in the electro-magnet is very weak, having merely a remnant left from that excited when the machine was last used. Some small *residual* magnetism, as it is termed, is, however, always present, and as this, when the machine is worked, generates currents in the armature coils, which in turn increase the magnetism, the full magnetic power required is obtained before the armature has made many revolutions.

When the whole of the current generated in the armature is taken through the coils of the field-magnets, the dynamo is called a *series wound* machine, as in this case armature coils, magnet coils, and external circuit are all connected in series. In some cases only a part of the current generated in the armature is passed through the magnet coils, the latter being connected in a branch circuit across the brushes. Such an arrangement is call ed a *shunt*, and dynamos excited on this plan are said to be *shunt-wound.*

Sometimes both arrangements are used in combination, the magnets being wound with two separate coils, one in series with the armature, and one in a shunt circuit, and the dynamos are then termed *compound wound.*

When electric currents are produced by means of a galvanic battery, zinc is consumed in the latter, and since apparently nothing is consumed in dynamo machines, it is not unnatural to enquire where the electric currents come from.

If the ends of the wire on the armature of one of these machines are not connected together in any way, so that it is impossible for any current to pass, and therefore none can be generated, it will be found that the power required to drive the armature at a given speed is very much less than when these ends are joined together and electric currents are being produced. In other words, the power absorbed by the machine is much greater when it is producing electric currents than when it is not so doing.

The fact is that the electric currents generated are derived direct from the power exerted by the steam engine or other motor which turns the armature, the dynamo machine acting merely the part of a converter of the mechanical energy exerted by the motor into electric energy or currents. In fact a dynamo generates a current of elec-

tricity in a manner similar to that in which a pump produces a current of water. In either case a prime motor of some kind or other is necessary to supply the initial power.

ELECTRIC LAMPS.

The principal methods of producing electric currents having been described, there remains the question of employing these currents to produce light.

Arc lamps.—When two pointed pencils or rods of gas carbon are connected by means of conducting wires with the poles of a large battery or dynamo machine in action, and the carbon points having been brought in contact with one another, so as to complete the electric circuit, are parted to the extent of about one-eighth of an inch, the electric current is not interrupted, as might be expected, but continues to flow across the intervening space, while the carbon points become intensely heated, and a discharge, or *arc*, as it is called, of white-hot particles of carbon fly across from one point to the other. If the electric current is strong, a light of extreme brilliancy is produced, which is due both to the arc and also, and more particularly, to the white-hot ends of the carbon pencils, which glow with extraordinary splendour.

Fig. 11.—Electric Arc.

As the action continues the pencils gradually burn away, and when the interval between them becomes too long the current suddenly ceases, and the light goes out. Arc lamps are arranged so that this extinction does not in practice occur, as by means of clockwork or electro-magnetic arrangements, the pencils are caused to move towards one another at exactly the same speed as they are consumed, and so the arc is maintained of a constant length. There is also generally a contrivance so that if by any chance

the light should go out, the pencils are instantaneously brought in contact again and once more immediately separated, so that a momentary blink is all that can take place.

Arc lamps are the most economical means of producing light from electric currents—that is to say, by employing them you can get more light for a given expenditure of power than in any other way; on the other hand, the light is often unsteady and of a peculiar bluish colour, while it is too intense and concentrated for many purposes. For these reasons arc lamps are as a rule only employed for out-door use and for lighting workshops and other large spaces.

The most usual sizes of arc lamps give a light of from 1,000 to 3,000 candle-power, but very large ones, giving as much as 25,000 candle-power, are employed for the search lights used on board war-ships.

Incandescent lamps are employed where a smaller amount of light is required, and where absolute steadiness is also necessary.

When an electric current passes through a wire the latter is heated. If the wire be of a uniform cross-section, and of the same material throughout—that is to say, if its electrical resistance be uniform throughout its entire length—the heat produced will be uniformly distributed. Should, however, the wire be thinner at one particular point, or be in one place made of a material of higher electrical resistance than the remainder, the thin or more highly resisting portion will become much more intensely heated than the rest.

In an arc lamp the interval between the points of the carbons and the points themselves are of much higher resistance than the rest of the circuit, and hence the heating effect is concentrated in and about the arc. In incandescent lamps there is no arc or apparent break in the complete continuity of the circuit, but a portion of the latter is made of an infusible material of high resistance, which becomes sufficiently heated to give the requisite illuminating power.

If a strong electric current be caused to flow through a length of fine platinum wire, the latter, owing to its high electrical resistance, will become heated to a white-hot temperature, and will evolve a certain amount of light.

Platinum melts too readily to be of any use for practical illumination, and fine wires, or *filaments* of carbon, formed by carbonising or charring in a closed retort at a white heat

pieces of cotton thread, strips of bamboo cane, or other suitable vegetable substance, are employed instead. These, when enclosed in an air-tight glass globe, from which as much as possible of the air has been removed by a special pump, can, by passing through them an electric current of suitable strength, be raised without injury to an extremely high temperature, and then become incandescent, or white-hot to the degree necessary to form an efficient source of light. The two ends of the filament, which is sometimes in the form of a horseshoe and sometimes in that of a loop, are attached to two platinum wires, which are separately sealed into and project out of the glass globe, and being connected with the wires from the dynamo machine or battery, serve to convey the electric currents to the filament, the current entering at one, and after passing through the filament, leaving at the other. Though there is no arc or actual consumption of the carbon, as with the arc form of lamp, the filament is found not to last for ever, and after a time it invariably gives way, and the entire lamp requires to be replaced. This durability depends in great measure on the temperature to which the filament is heated. If raised to a very high temperature by means of a strong current the filament may fail immediately, and at all events it will last for a very much shorter time than had a weaker current and a lower temperature been employed. At the same time the efficiency of the lamp will be greater in the former than in the latter case; that is to say, that with a given expenditure of power more light is obtained by raising the filament to a high temperature, and less when the temperature is lower. In no case, however, does the efficiency of an incandescent lamp equal that of the arc form.


Fig. 12.—Incandescent Lamp.

Incandescent lamps are made of various sizes, and recently some have been brought out that give as much as 500 candle-power each. The more ordinary kinds, however, are of 8, 16, 32, and 50 candle-power respectively. An incandescent lamp, with holder and screw attachments for the wires, is shown in Fig. 12.

ELECTRIC LIGHTING INSTALLATIONS.

Having seen how electric currents can be produced, and also how these currents can be utilised to give light in arc or incandescent lamps, there remains the question of leading the electric currents from the generator to the lamps. An installation must comprise at least three parts.

1st. The electric generator, consisting of a galvanic battery, or, as is more generally the case for electric lighting, a dynamo machine, driven by a steam or gas engine, a water-wheel, or other source of power.

2nd. The conductors, or wires that convey the electric currents fr*ó*m the generator to the lamps.

3rd. The lamps, in which the electric currents are converted into light.

As previously mentioned, electric currents flow in complete circuits, and hence it is not only necessary to provide a wire to convey the current to the lamp, but it is likewise requisite that there should be also a means for the current after it has passed through the latter to return to the generator.

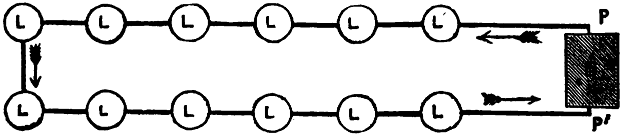

Fig. 13.—Arrangement of Lamps in Series.

Fig. 13 shows how arc lamps are often arranged. Here D is a dynamo machine with its two poles P P′, and L L, &c., are the lamps. The current passes out from the dynamo at P and flows through all the lamps one after the other in the direction of the arrows, returning again to the dynamo at P′.

This arrangement is called connecting the lamps in *series*, and it is evident that should one of the lamps be by any means extinguished and the current thereby interrupted, all the other lamps on the circuit will also go out.

Incandescent lamps are generally connected to the dynamo as shown in Fig. 14, and arc lamps are also sometimes arranged in like manner. The large wires P Q and P′ Q′ are called the

main leads or *mains*, and the lamps are arranged in what are called *shunt* or *derived* circuits between these, the whole being termed an arrangement in *parallel circuits*. Here every individual lamp draws off a certain amount of electric current, and is quite independent of its neighbours.

Should the circuit be broken at P or P′, all the lamps will be extinguished, but one lamp can be put out without interfering with the rest by interrupting one of the small wires with which it individually is connected.

For a lamp to burn uniformly it is evident that the current flowing through it must be maintained at a constant strength. When lamps are arranged in series as in Fig. 13, any addition to the number of lamps on the circuit adds to the total resistance of the latter, and the electric pressure, or E.M.F.,

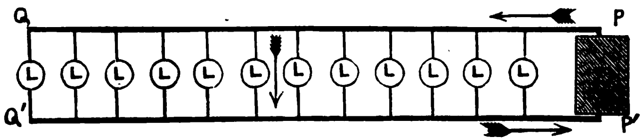

Fig. 14.—Arrangement of Lamps in Parallel Circuits.

must be increased in proportion in order that the strength of the current and the brilliancy of the lamps may be maintained constant.

With the parallel circuit arrangement, on the other hand, when lamps are added the total resistance is decreased, and if the E.M.F. be kept constant, the quantity or strength of current will increase and the lamps will burn as brightly as before. While the series system therefore necessitates the maintenance of a constant current the parallel arrangement requires a constant E.M.F. In order to effect these necessary regulations of the current special governors or regulators are sometimes employed, but in many cases the necessary results can be obtained by simply taking advantage of the varying degrees of magnetism that are imparted to the field magnets of the dynamo by the several different arrangements—series, shunt, and compound—of winding them already described.

As resistance in the conductors means waste of potential and power, the conducting wires for electric lighting are almost invariably made of copper, which is one of the best conduc-

tors of electricity, and in order to prevent the currents from leaving the wires and taking a short cut back to the dynamo instead of passing through the lamps, they are usually covered with an insulating coat of india-rubber and tape. Larger wires are necessary for large currents than for small ones, and if the wires are too small they will become heated, and may even become red-hot and melt. Again, the amount of insulation should be increased with the E.M.F., as when the latter is high there is a greater tendency for the current to leak across from one wire to the other and avoid passing through the lamps. Moreover, currents of very high E.M.F. give dangerous electric shocks to any person touching the bare conductors, and hence the wires should be well covered to prevent any possibility of accident.

The currents employed with incandescent lamps are, however, seldom of sufficient E.M.F. to be actually dangerous to life, though they may give decidedly unpleasant shocks; and it is, as a rule, only with arc lamps connected in series and on systems for electric distribution by means of transformers, that special precautions are necessary on this account.

For the purpose of extinguishing individual lamps or groups of them, *switches* are employed. They are merely contrivances by means of which the metallic continuity of the circuit can be broken and re-made with facility, the electric current in that circuit being thereby arrested or restored. Switches should be arranged to break circuit sharply, so as to prevent the formation of an electric arc between the contact surfaces, which might thus be fused and destroyed, and for large currents it is best that the circuit should be interrupted at two distinct points at once.

Safety fuses, *safety plugs*, or *cut-outs*, as they are variously called, are devices for preventing the undue heating of the wires should any accident, such as a *short-circuit—i.e.*, accidental metallic connection between positive and negative wires—cause the current to become too large. They consist of small portions of lead, tin, or fine copper wire inserted in the circuit, which, being very thin and therefore of comparatively high resistance, become heated and readily melt and interrupt the current when the latter increases beyond a given strength.

In Fig. 15 we have a complete electric lighting system of lamps in parallel circuits, with dynamo, switches, fuses, and conductors.

D is as before the dynamo, with its positive and negative poles P and P′. M S is a main switch, which by breaking the main leading wire turns off the whole of the lamps at once. M F is a main fuse, which will only act under very exceptional circumstances, such as a short circuit between the main leading wires, and will then cut off the entire current and extinguish all the lights. S S, &c., are the branch switches, and F F the branch fuses.

Circuit *a* contains but a single lamp which has a switch and fuse all to itself, so that it can be extinguished without affecting the others, of which it is entirely independent. Circuit *b* contains four lamps, themselves in parallel circuit. This circuit has only one switch and one fuse, so that all the

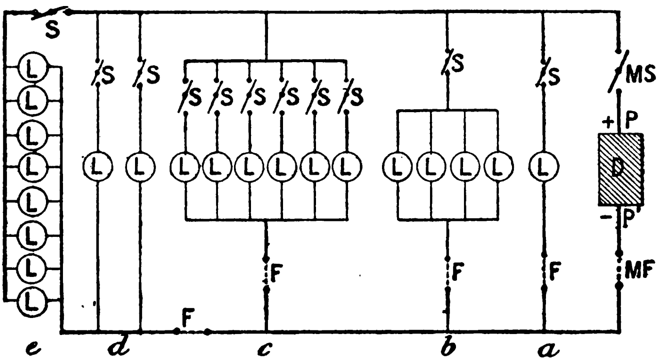

Fig. 15.—Complete Electric Lighting System.

lamps must be turned off at once; and if any accident causes the fuse to melt, all four lamps will be extinguished. Circuit *c* consists of six lamps, each of which has a switch to itself, and can be separately put out; there is, however, only one fuse for the six lamps.

Circuits *d* and *e* are dependent upon one and the same fuse, but each of the two lamps in *d* has a switch to itself, and the eight lamps in *e* are turned on or off simultaneously by another.

These several circuits show the different arrangements that are found convenient in practical work.

The position of lamps, switches, fuses, and lead of wires, as well as the general disposition of circuits, are of course

dependent upon circumstances, and can be arranged according to convenience.

ELECTRIC ACCUMULATORS.

Electric accumulators, or storage or secondary batteries, are appliances for the electrical storage of power.

When electric lamps are fed direct by dynamo machines, the latter require to be kept in constant operation, as the moment they stop the electric currents they generate cease and the lamps go out. The employment of accumulators overcomes this difficulty.

A simple storage battery consists of two lead plates immersed in a dilute solution of sulphuric acid and water. When an electric current is caused to pass between the plates, one of them, the one attached to the positive pole of the generator, is chemically acted upon and assumes a dark brown colour. If after the charging current has been allowed to pass for some time, the plates are disconnected from the generator, and are put in circuit with a galvanometer, a deflection of the needle of the latter will show that an electric current is now passing from the brown plate through the galvanometer and back again to the other plate, the brown and the other plate acting respectively the parts of the copper and zinc plates in the simple galvanic battery described on page 16.

The current thus obtained is always in the opposite direction to that employed in the first instance to charge the battery, and it is never possible to get as much out as is put in, there being invariably a certain percentage of loss. The duration of the secondary current depends on the length of time during which the cells were charged, and after discharging for a certain period the current will entirely cease and the battery requires to be charged once more.

A single cell such as described will only give a very small current for a short time, but by specially preparing the lead plates, and by employing a large number of them, and also by connecting a great many such separate cells together, and charging them with a powerful dynamo machine for a long time, sufficient current can be stored to maintain many electric lamps for a considerable number of hours.

It should be clearly understood that the electric currents employed to charge these batteries are not really themselves

stored up in the cells, but are merely caused to perform chemical work in altering the chemical constitution of the surfaces of the two lead plates, and that the secondary currents are entirely due to this alteration in the lead, which, as the discharge continues, gradually returns to its former condition; and when this state is finally reached the battery is exhausted, and until it is re-charged is incapable of producing any further current.

Storage batteries are frequently employed in electric lighting installations to maintain the lamps in case of a possible breakdown of the dynamo machine, which would otherwise entail the extinction of all the lamps; and also as regulators, to prevent fluctuations in the speed of the dynamo from affecting the steadiness of the light. It is also often convenient to run the dynamo during the day to charge the batteries, the latter feeding the lamps in the evening and throughout the night as required. The dynamos used for charging storage batteries must be of the kind giving currents continuously in one direction. Alternating current dynamos are useless for this purpose.

ELECTRIC TRANSFORMERS.

Electric transformers, or secondary generators, as they are sometimes called, are appliances employed for converting electric currents of high E.M.F. and small quantity into currents of low E.M.F. and large quantity.

As we have already seen, incandescent lamps are most conveniently arranged in parallel circuit, this requiring strong currents of comparatively low E.M.F.

Such currents, however, require very large mains to conduct them without overheating and loss of potential, and as these mains must be of copper, where the distances between the dynamo and lamps are considerable, they are very costly.

Transformers are used to meet this difficulty. We have seen how momentary electric currents are induced in a coil of wire wound on an iron rod, when the latter is magnetised by the approach of a magnet, and also that an iron rod wound with insulated wire is magnetised when an electric current is passed through the wire. If then an iron rod be wound with two coils, and a current is passed through one of them so as to excite magnetism in the rod, it is clear

that a corresponding current will be induced in the other coil. This induced current will be momentary, lasting only so long as the iron bar takes to magnetise; but if the inducing current be periodically interrupted, or better still, if an alternating current is used to magnetise the bar, the induced current will also be alternating, and will continue to flow as long as the magnetising current passes.

Transformers work on this principle, and consist simply of two coils of wire wound on a suitable iron core. The inducing coil, which is in circuit with the alternate-current

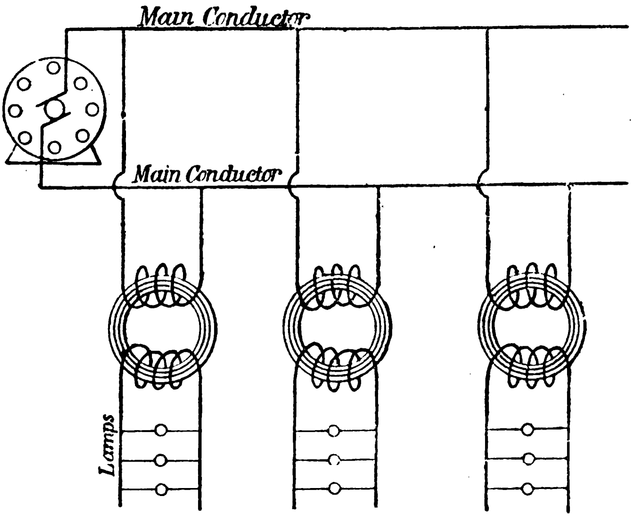

Fig. 16.—Arrangement of Transformers.

dynamo employed to supply the electric currents, is called the *primary*, while the other coil, which is put in circuit with the lamps, is called the *secondary*.

By making the primary coil of many turns of wire, and the secondary of comparatively few turns and low resistance, the induced or secondary currents are obtained of much lower E.M.F. and larger strength than the primary currents.

By this means currents of very high E.M.F. and small quantity, which can easily be transmitted over long distances through comparatively small wires, are when they

arrive at the lamps converted into currents of much larger quantity and lower E.M.F., such as the lamps require.

Fig. 16 shows the general arrangement of such a system, the dynamo which is in the left-hand top corner supplying current to three transformers with their primary and secondary circuits, wound upon ring-shaped iron cores.

INDEX.

THE END.

PRINTED BY J. S. VIRTUE AND CO., LIMITED, CITY ROAD, LONDON.